# PART 4. SCIENCE VALIDATION

# 1. INTRODUCTION

The EO-1 mission is a technology mission whose primary objective has been to demonstrate and evaluate selected advanced technologies carried aboard the spacecraft. This demonstration has been carried out in the context of meeting Earth science needs in the 21st century that would enhance the capabilities and reduce the cost of obtaining Landsat-like data. A secondary but still important objective has been to demonstrate imaging spectrometer instrument technology and explore Earth science applications of hyperspectral data that relate to future requirements of NASA's Earth Science Enterprise.

Science validation related to these objectives has been ongoing since shortly after the launch of EO-1 in November 2000 under the auspices of the Biospheric Sciences Branch, Laboratory for Terrestrial Physics of the Earth Sciences Directorate at NASA's Goddard Space Flight Center. The emphasis of the validation has been on characterizing the performance of the EO-1 instruments in acquiring remotely sensed measurements that contribute to a variety of important earth science applications. The pervasive theme of EO-1's science validation activity is objective (quantitative) validation through comparison with data gathered by the Enhanced Thematic Mapper (ETM+) on board the Landsat 7 satellite and by airborne and ground-based systems.

## 1.1 Background

In 1996, a Science Advisory Team was formed by NASA's Earth Science Enterprise. This team, which consisted of scientists from GSFC, NASA Headquarters, and members of the academic and private-sector science community, identified science requirements that could be used to evaluate how well the technology on-board EO-1 performed. The team also provided input to the EO-1 mission as to which technologies would be best suited to achieve the science objectives and ranked the technologies in terms of their scientific potential and the mission risks that they posed. Furthermore, the science team and the EO-1 mission cooperatively determined that the orbit of the EO-1 spacecraft would match within one minute the Landsat 7 ground track so that both instruments would be able to collect near simultaneous images of the same location.

In April 1999 NASA and the U.S. Geological Survey (USGS) of the Department of the Interior released a joint solicitation, NASA Research Announcement NRA-99-OES-01, for scientific investigations to validate the New Millennium Program's EO-1 mission technologies and to assess EO-1 hyperspectral imaging for science and application research. Proposals were to address the following objectives:

1) To evaluate the selected EO-1 technologies with respect to their ability to meet the needs for future Landsat-class observations at reduced cost and with enhanced quality.

2) To evaluate space-based imaging spectrometers for potential future NASA and USGS scientific, applied, and commercial uses of hyperspectral data.

3) To evaluate the implications, for data correction and calibration, of new ways of conducting missions such as: formation flying with other satellites, approaches to inter-satellite and lunar calibration and atmospheric correction, and autonomous navigation/instrument operation.

Of the 115 proposals for scientific investigations that were submitted, NASA HQ and the USGS selected 31 (see Section 1.5). The associated Principal Investigators (PI's) formed the core of the Science Validation Team (SVT). Other members of the SVT were GSFC and NASA Headquarters Project Scientists (ex officio); a lead from each instrument team; representatives from the USGS; the Commercial

Remote Sensing Program at NASA's Stennis Space Center; and the Argentinean CONAE (Comisión Nacional de Actividades Espaciales). The team evaluated the following three instruments on board EO-1: the Advanced Land Imager (ALI), the Hyperion, and the Linear Etalon Imaging Spectral Array (LEISA) Atmospheric Corrector (LAC).

### 1.2 Methodology

The orbits of EO-1 and Landsat 7 have allowed the two satellites to collect identical images for later comparison on the ground. EO-1 traces the same ground track as Landsat 7 but one minute later. All three EO-1 land imaging instruments view all or sub-segments of the Landsat 7 ground swath and transmit their recorded data to the ground when within range of a ground station for temporary storage and shipment to GSFC.

The particular scenes acquired have been selected based on the needs of the investigators, the EO-1 mission team, the USGS, and other partners in the validation effort.

Science validation began soon after initial instrument checkout following the November 21, 2000 launch. Initial investigations focused on the Southern Hemisphere, where it was summer, so that a sizable amount of data could be gathered under conditions of relatively high solar illumination. This would allow the study of a large variety of landscapes representative of varying stages of vegetative development that are of global significance. The specific objectives of this validation effort were:

1. Acquisition of data from appropriate ground targets
2. Trending of instrument responses
3. Data calibration

Extensive fieldwork, supported by the HYMAP airborne spectral imager, was conducted in Australia beginning soon after launch through the first 120 days in orbit. Additionally, from early January through February 2001, an intensive field campaign was conducted in Argentina. These were supported by U.S. and Argentinean investigators conducting AVIRIS spectral imager overflights using Twin Otter turboprop and ER-2 jet aircraft. Members of the Science Validation Team also made measurements at additional Southern Hemisphere sites in New Zealand and Africa.

Science data-gathering activities were essentially complete at the end of calendar year 2001, although some data continued to be collected through January 2002 to augment and enhance the validation. During this time, called the "base mission" period, the mission captured information over full growing seasons for both the Southern and Northern Hemispheres.

### 1.3 Extended Mission

In November 2001, NASA Headquarters approved extending the mission life of EO-1, reaching an agreement between NASA and the USGS. This was in response to many requests for data acquisitions beyond those collected as part of the base mission validation effort. During the Extended Mission, EO-1 resources are being made available to the larger user community, beyond the Science Validation Team. Beginning with the Extended Mission, acquisition planning and scheduling, as well as data processing and distribution responsibilities, were transferred to the USGS EROS Data Center (EDC). EDC also assumed responsibility for all customer services related to the acquisition, archiving, and distribution of EO-1 image data. Selection and collection of scenes are at the direction of the USGS EDC in response to customer requirements. The EO-1 Science Validation Team, however, continues occasionally to request that particular scenes be captured when earlier efforts to collect specific scenes did not yield satisfactory results or circumstances at the time of the data collection prevented acquiring usable data.

The Extended Mission phase began officially in February 2002.

## 1.4 Science Validation Investigations

Each PI or team of investigators led by a PI has carried out scientific investigations according to the terms set forth in NRA-99-OES-01 for the EO-1 Validation Program. In general, these investigations focused on comparisons of EO-1-derived data with Landsat 7 data or with data captured by airborne or ground-based systems as they related to specific science applications. They also focused on how well the instruments functioned in relation to their stated specifications when used to acquire data in the field.

In particular, individual investigations focused on one or more of the following:

- The ability of the ALI to produce calibrated, multispectral images of the Earth's surface.
- The utility of Hyperion data for synthesizing Landsat-like multispectral bands.
- An analysis of particular science and applications uses of hyperspectral data.
- A comparison of Hyperion performance with that of other satellite sensors, in particular the ability to use Hyperion's high spectral and moderate spatial resolution to produce better quality data products than those available through Landsat sensors or other relevant satellite instruments
- The ability to analyze the quality of atmospheric corrections through the use of data from the LAC.
- Determining the potential for improving land surface data by applying LAC-derived atmospheric water vapor corrections to Landsat 7 ETM+ as well as EO-1 ALI observations.
- The quality and validity of derived data products produced with EO-1 data.
- ALI, Hyperion, and/or LAC sensor performance.
- The efficacy of different calibration modes, including solar calibration, lunar calibration, and inter-satellite cross-calibration.

Investigators were asked to report their objectives and conclusions in a short summary that they submitted to the GSFC EO-1 Mission Scientist. These summaries stated the objective of the investigation and the conclusions. In addition, many investigators have generated publications and made presentations during the course of their studies. The summaries section that follows (Section 3) presents synopses of these investigations.

## 1.5 Selected Proposals Under NRA-99-OES-01 for the EO-1 Validation Program

1. **Abrams, M. J.**, Jet Propulsion Laboratory; R. Bianchi and L. Alberotanza, National Research Council, Italy.
   - *Applications and Validation of EO-1 Data for Oceanography, Pollution and Urban Mapping.*
2. **Asner, G. P.**, University of Colorado and M. Keller, United States Department of Agriculture Forest Service.
   - *Low-Cost Evaluation of EO-1 Hyperion and ALI for Detection and Biophysical Characterization of Forest Logging in Amazonia.*
3. **Asner, G. P.**, C. A. Wessman, and C. A. Bateson, University of Colorado.
   - *Analysis of EO-1, Landsat 7, and AVIRIS for Estimating Vegetation Structure and Function in Arid Ecosystems.*
4. **Biggar, S. F.**, R. Schowengerdt, E. Zalewski, and K. Thome, University of Arizona, and G. Lemeshewsky, United States Geological Survey.
   - *Radiometric Calibration, Spatial Characterization, and Spectral Evaluation of the Advanced Land Imager and Hyperion Sensors.*
5. **Bindschadler, R.** and D. Hall, NASA Goddard Space Flight Center; M. Fahnestock, University of Maryland; and A. Nolin, T. Scambos, and J. Stroeve, University of Colorado.
   - *Advancing Glaciological Applications of Remote Sensing with EO-1.*
6. **Boardman, J. W.**, Analytical Imaging and Geophysics, LLC; R. Crabtree, Yellowstone Ecosystem Studies; and D. Despain, United States Geological Survey.

   - *Validation and Application of Hyperion Imaging Spectrometry Data via Ecological Applications in Yellowstone National Park.*
7. **Carlson, B. E.**, A. Lacis, and M. Mishchenko, NASA Goddard Institute of Space Studies; and M. Alexandrov and B. Cairns, Columbia University.
   - *Correlative Analysis of EO-1, Landsat, and Terra Data of the DOE ARM CART Sites: An Investigation of Instrument Performance and Atmospheric Correction.*
8. **Cassady, P. E.** and D. Nichols, Boeing Phantom Works; E. M. Perry, Battelle Pacific Northwest Division; and D. Roberts, University of California, Santa Barbara.
   - *Hyperspectral EO-1 Data Request for Earth Observation Commercial Applications Program.*
9. **Crowley, J. K.**, United States Geological Survey; R. J. Watters, University of Nevada at Reno; and D. R. Zimbelman, G. O. Logic, Inc.
   - *Global Assessment of Volcanic Debris flow Hazards from Space: Evaluation of New Multispectral and Hyperspectral Satellite Systems.*
10. **Flynn, L.** and A. Harris, University of Hawaii.
    - *Quantitative Analysis of Hot Spots Using EO-1 and Landsat 7.*
11. **Goetz, A. F. H.**, and Z. Qu , University of Colorado.
    - *EO-1 Evaluation and Verification for Application to Land-use and Land-use Change: Atmospheric Correction, Soils and Sparse Vegetation Mapping.*
12. **Gong, P.** and G. S. Biging, University of California, Berkeley.
    - *EO-1 and Landsat Imagery for Monitoring California's Conifer Forest and Hardwood Rangeland.*
13. **Goodenough, D. G.**, R. Hall, J. Iisaka, D. Leckie, K. Staenz, A. S. Bhogal, and A. Dyk, Natural Resources Canada; A. Hollinger, Canadian Space Agency; J. Miller, York University; K. O. Niemann, University of Victoria; and H. Zwick, MacDonald Dettwiler.
    - *Evaluation and Validation of EO-1 for Sustainable Development of National Forests (EVEOSD).*
14. **Huete, A. R.**, D. X. Kerola, and M. Susan Moran, University of Arizona.
    - *Inter-Sensor Calibration of Vegetation Indices for Monitoring and Continuity Studies.*
15. **Jupp, D. L. B.**, J. Huntington, T. Cudahy, A. Held, D. Graetz, and G. Pickup, Commonwealth Scientific and Industrial Research Organisation (Australia); C. Smith, Australian Centre for Remote Sensing; and T. Cocks, Integrated Spectronics Ltd.
    - *Evaluation of Hyperion Performance at Australian Hyperspectral Calibration and Validation Sites.*
16. **Kieffer, H.**, United States Geological Survey.
    - *Participation in the Characterization and Calibration of New Millennia Spacecraft.*
17. **Kruse, F. A.** and J. W. Boardman, Analytical Imaging and Geophysics LLC and J. F. Huntington, Commonwealth Scientific and Industrial Research Organisation.
    - *Evaluation and Geologic Validation of EO-1 Hyperion.*
18. **Liang, S.**, F. Huemmrich, and J. Morisette, University of Maryland and C. Walthall and C. Daughtry, United States Department of Agriculture Agricultural Research Service.
    - *EO-1 Validation and Evaluation for Agricultural Monitoring.*
19. **Liew, S. C.**, G. Lee, and O. K. Lim, National University of Singapore and L. Chan and I. M. Turner, National Parks Board, Singapore.
    - *Applications of EO-1 Hyperion and ALI Data in Tropical Forest Classification and Burn Scars Mapping.*
20. **Martin, M.** and J. Aber, University of New Hampshire and M. L. Smith, United States Department of Agriculture Forest Service.
    - *Evaluation of Hyperspectral Requirements for Remote Estimation of Forest Ecosystem Composition and Function.*

21. **Matsunaga, T.**, Tokyo Institute of Technology; A. Iwasaki, Electro-Technical Laboratory; and S. Tsuchida, Geological Survey of Japan.
    - *Coastal and Inland Water Environmental Monitoring in Japan Using Hyperion Data.*
22. **McGwire, K.** and B. Schultz, Desert Research Institute.
    - *A Combined Investigation: Hyperspectral Monitoring of Invasive, Non-Native Plant Species with EO-1 Hyperion Imagery.*
23. **Meyer, D. J.**, T. DeFelice, J. Storey, D. Steinwand, R. Morfitt, M. Choate, and J. Vogelmann, United States Geological Survey/EROS Data Center (Raytheon); D. Helder and S. Schiller, South Dakota State University; and T. Loveland, United States Geological Survey/EROS Data Center.
    - *An Integrated Assessment of the Earth Observer -1 Instrument Suite and the Landsat 7 Enhanced Thematic Mapper Plus.*
24. **Moran, M. S.** and D. Goodrich, United States Department of Agriculture Agricultural Research Service and A. Huete, University of Arizona.
    - *EO-1 and Landsat Inter-Satellite Comparison at Two Established Arizona Field Sites.*
25. **Mustard, J. F.**, Brown University.
    - *Precision and Accuracy of ALl Data for the Determination of Vegetation Abundance.*
26. **Ramsey III, E. W.**, United States Geological Survey.
    - *Integrating Hyperspectral and Landsat TM Data for Mapping the Invasive Species Chinese Tallow.)*
27. **Roberts, D. A.**, University of California, Santa Barbara; S. L. Ustin, University of California, Davis; and C. T. Lee, California State University, Dominguez Hills.
    - *Hyperion Applications and Validation for Fire Hazard Assessment in the Santa Monica Mountains, California.*
28. **Root, R**. United States Geological Survey; S. Hagar, National Park Service; S. Ustin, University of California, Davis; and G. Anderson, Agricultural Research Service.
    - *Detection and Mapping or Invasive Leafy Spurge Using Orbital Hyperspectral Imagery from the EO-1 Mission*
29. **Smith, J. A.**, NASA Goddard Space Flight Center.
    - *Synergistic Application of EO-1 and Landsat-7 for Canopy Temperature Estimation.*
30. **Townsend, P. A**., University of Maryland Center for Environmental Science Appalachian Laboratory.
    - *Remote Sensing of Forest Composition and Structure in the Central Appalachians using EO-1 Hyperspectral Data.*
31. **White, W. A**., J. A. Raney, and M. Crawford, The University of Texas at Austin.
    - *Evaluation and Validation of EO-1 and Landsat 7 Imagery through an Analysis of Land Cover/Land Use and Rates of Deforestation in Belize, Central America.*